Understanding Options

Pop quiz: What do the following events have in common?

- The coffee roaster, Green Mountain, buys options that put a ceiling on the price that it will pay for its future purchases of beans.
- Flatiron offers its president a bonus if the company's stock price exceeds $120.
- Blitzen Computer dips a toe in the water and enters a new market.
- Malted Herring postpones investment in a positive-NPV plant.
- Hewlett-Packard exports partially assembled printers even though it would be cheaper to ship the finished product.
- Dominion installs a dual-fired unit at its Possum Point power station that can use either fuel oil or natural gas.
- In 2004 Air France acquires the Dutch airline, KLM, in exchange for a package of Air France shares and warrants. The warrants entitle KLM's shareholders to buy additional Air France shares for €20 each within then next 3.5 years.
- In February 2008 Chiquita Brands issues $200 million of 4.25% convertible bonds maturing in 2016. Each bond can be exchanged for 44.55 shares at any time before maturity.

Answers: (1) Each of these events involves an option, and (2) they illustrate why the financial manager of an industrial company needs to understand options.

Companies regularly use commodity, currency, and interest-rate options to reduce risk. For example, a meatpacking company that wishes to put a ceiling on the cost of beef might take out an option to buy live cattle at a fixed price. A company that wishes to limit its future borrowing costs might take out an option to sell long-term bonds at a fixed price. And so on. In Chapter 26 we explain how firms employ options to limit their risk.

Many capital investments include an embedded option to expand in the future. For instance, the company may invest in a patent that allows it to exploit a new technology or it may purchase adjoining land that gives it the option in the future to increase capacity. In each case the company is paying money today for the opportunity to make a further investment. To put it another way, the company is acquiring *growth opportunities.*

Here is another disguised option to invest: You are considering the purchase of a tract of desert land that is known to contain gold deposits. Unfortunately, the cost of extraction is higher than the current price of gold. Does this mean the land is almost worthless? Not at all. You are not obliged to mine the gold, but ownership of the land gives you the option to do so. Of course, if you know that the gold price will remain below the extraction cost, then the option is worthless. But if there is uncertainty about future gold prices, you could be lucky and make a killing.[1]

If the option to expand has value, what about the option to bail out? Projects don't usually go on until the equipment disintegrates. The decision to terminate a project is usually taken by management, not by nature.

[1] In Chapter 11 we valued Kingsley Solomon's gold mine by calculating the value of the gold in the ground and then subtracting the value of the extraction costs. That is correct only if we *know* that the gold will be mined. Otherwise, the value of the mine is increased by the value of the option to leave the gold in the ground if its price is less than the extraction cost.

Once the project is no longer profitable, the company will cut its losses and exercise its option to abandon the project. Some projects have higher abandonment value than others. Those that use standardized equipment may offer a valuable abandonment option. Others may actually cost money to discontinue. For example, it is very costly to decommission an offshore oil platform.

We took a peek at investment options in Chapter 10, and we showed there how to use decision trees to analyze a pharmaceutical company's options to discontinue trials of a new drug. In Chapter 22 we take a more thorough look at these *real* options.

The other important reason why financial managers need to understand options is that they are often tacked on to an issue of corporate securities and so provide the investor or the company with the flexibility to change the terms of the issue. For example, in Chapter 24 we show how warrants or convertibles give their holders an option to buy common stock in exchange for cash or bonds.

In fact, we see in Chapter 23 that whenever a company borrows, it gains an option to walk away from its debts and surrender its assets to the bondholders. If the value of the company's assets is less than the amount of the debt, the company will choose to default on the payment and the bondholders will get to keep the company's assets. Thus, when the firm borrows, the lender effectively acquires the company and the shareholders obtain the option to buy it back by paying off the debt. This is an extremely important insight. It means that anything that we can learn about traded options applies equally to corporate liabilities.

In this chapter we use traded stock options to explain how options work, but we hope that our brief survey has convinced you that the interest of financial managers in options goes far beyond traded stock options. That is why we are asking you to invest here to acquire several important ideas for use later.

If you are unfamiliar with the wonderful world of options, it may seem baffling on first encounter. We therefore divide this chapter into three bite-sized pieces. Our first task is to introduce you to call and put options and to show you how the payoff on these options depends on the price of the underlying asset. We then show how financial alchemists can combine options to produce a variety of interesting strategies.

We conclude the chapter by identifying the variables that determine option values. There you encounter some surprising and counterintuitive effects. For example, investors are used to thinking that increased risk reduces present value. But for options it is the other way around.

20-1 Calls, Puts, and Shares

Investors regularly trade options on common stocks.[2] For example, Table 20.1 reproduces quotes for options on the stock of Google. You can see that there are two types of option—calls and puts. We explain each in turn.

Call Options and Position Diagrams

A **call option** gives its owner the right to buy stock at a specified *exercise* or *strike price* on or before a specified maturity date. If the option can be exercised only at maturity, it is conventionally known as a *European call;* in other cases (such as the Google options shown in Table 20.1), the option can be exercised on or at any time before maturity, and it is then known as an *American call.*

The third column of Table 20.1 sets out the prices of Google call options with different exercise prices and exercise dates. Look at the quotes for options maturing in

[2] The two principal options exchanges in the United States are the International Securities Exchange (ISE) and the Chicago Board Options Exchange (CBOE).

TABLE 20.1 Selected prices of put and call options on Google stock in September 2008, when the closing stock price was $430.

Maturity Date	Exercise Price	Price of Call Option	Price of Put Option
December 2008	$370	$ 78.90	$16.45
	400	58.65	26.10
	430	41.75	38.90
	460	28.05	55.45
	490	17.85	75.45
March 2009	$370	$ 90.20	$25.05
	400	70.80	35.65
	430	**54.35**	**48.55**
	460	39.85	64.10
	490	28.75	83.20
January 2010*	$370	$116.90	$42.55
	400	100.00	54.75
	430	85.05	69.85
	460	71.60	86.00
	490	59.90	103.70

* Long-term options are called "LEAPS."

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December 2008. The first entry says that for $78.90 you could acquire an option to buy one share[3] of Google stock for $370 on or before December 2008. Moving down to the next row, you can see that an option to buy for $30 more ($400 vs. $370) costs $20.25 less, that is $58.65. In general, the value of a call option goes down as the exercise price goes up.

Now look at the quotes for options maturing in March 2009 and January 2010. Notice how the option price increases as option maturity is extended. For example, at an exercise price of $430, the December 2008 call option costs $41.75, the March 2009 option costs $54.35, and the January 2010 option costs $85.05.

In Chapter 13 we met Louis Bachelier, who in 1900 first suggested that security prices follow a random walk. Bachelier also devised a very convenient shorthand to illustrate the effects of investing in different options. We use this shorthand to compare a call option and a put option on Google stock.

The *position diagram* in Figure 20.1(*a*) shows the possible consequences of investing in Google March 2009 call options with an exercise price of $430 (boldfaced in Table 20.1). The outcome from investing in Google calls depends on what happens to the stock price. If the stock price at the end of this six-month period turns out to be less than the $430 exercise price, nobody will pay $430 to obtain the share via the call option. Your call will in that case be valueless, and you will throw it away. On the other hand, if the stock price turns out to be greater than $430, it will pay to exercise your option to buy the share. In this case, when the call expires, it will be worth the market price of the share minus the $430 that you must pay to acquire it. For example, suppose that the price of Google stock rises to $500. Your call will then be worth $500 − $430 = $70. That is your payoff, but of course it is not all profit. Table 20.1 shows that you had to pay $54.35 to buy the call.

[3] You can't actually buy an option on a single share. Trades are in multiples of 100. The minimum order would be for 100 options on 100 Google shares.

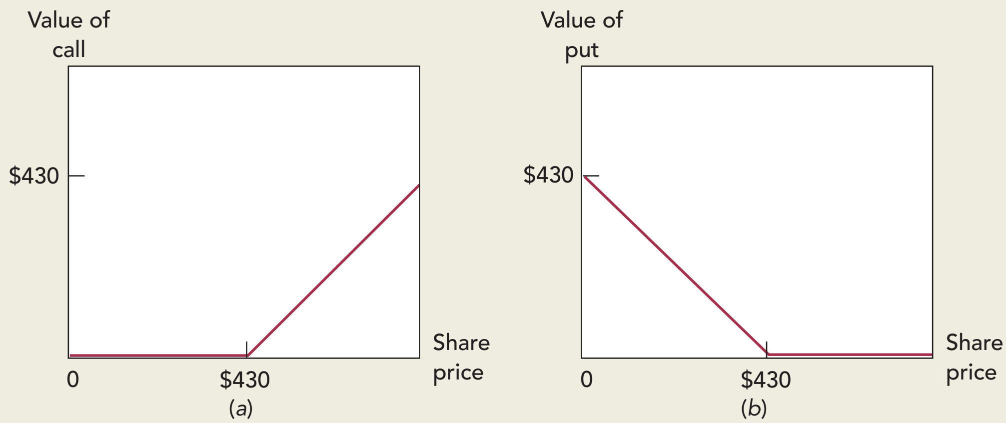


FIGURE 20.1

Position diagrams show how payoffs to owners of Google calls and puts (shown by the colored lines) depend on the share price. (*a*) Result of buying Google call exercisable at $430. (*b*) Result of buying Google put exercisable at $430.

Put Options

Now let us look at the Google **put options** in the right-hand column of Table 20.1. Whereas a call option gives you the right to *buy* a share for a specified exercise price, a put gives you the right to *sell* the share. For example, the boldfaced entry in the right-hand column of Table 20.1 shows that for $48.55 you could acquire an option to sell Google stock for a price of $430 anytime before March 2009. The circumstances in which the put turns out to be profitable are just the opposite of those in which the call is profitable. You can see this from the position diagram in Figure 20.1(*b*). If Google's share price immediately before expiration turns out to be *greater* than $430, you won't want to sell stock at that price. You would do better to sell the share in the market, and your put option will be worthless. Conversely, if the share price turns out to be *less* than $430, it will pay to buy stock at the low price and then take advantage of the option to sell it for $430. In this case, the value of the put option on the exercise date is the difference between the $430 proceeds of the sale and the market price of the share. For example, if the share is worth $340, the put is worth $90:

$$\begin{aligned}\text{Value of put option at expiration} &= \text{exercise price} - \text{market price of the share}\\ &= \$430 - \$340 = \$90\end{aligned}$$

Selling Calls, Puts, and Shares

Let us now look at the position of an investor who *sells* these investments. If you sell, or "write," a call, you promise to deliver shares if asked to do so by the call buyer. In other words, the buyer's asset is the seller's liability. If the share price is below the exercise price when the option matures, the buyer will not exercise the call and the seller's liability will be zero. If it rises above the exercise price, the buyer will exercise and the seller must give up the shares. The seller loses the difference between the share price and the exercise price received from the buyer. Notice that it is the buyer who always has the option to exercise; option sellers simply do as they are told.

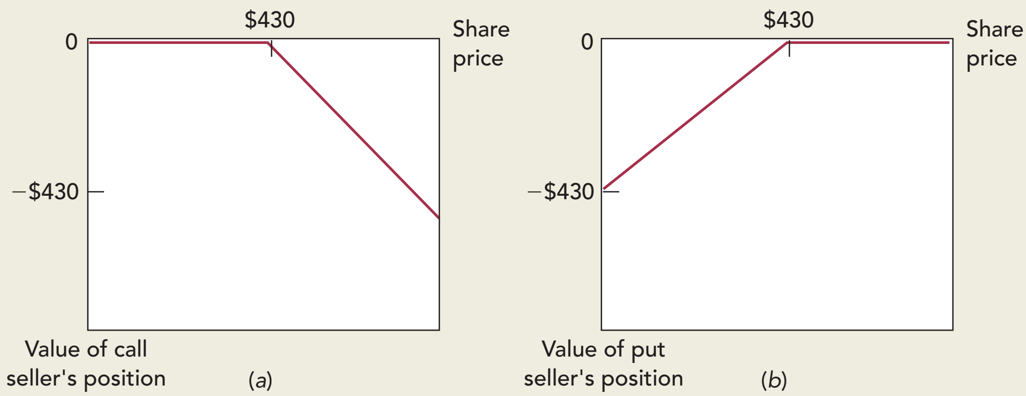


FIGURE 20.2

Payoffs to *sellers* of Google calls and puts (shown by the colored lines) depend on the share price. (*a*) Result of selling Google call exercisable at $430. (*b*) Result of selling Google put exercisable at $430.

Suppose that the price of Google stock turns out to be $500, which is above the option's exercise price of $430. In this case the buyer will exercise the call. The seller is forced to sell stock worth $500 for only $430 and so has a payoff of −$70.[4] Of course, that $70 loss is the buyer's gain. Figure 20.2(*a*) shows how the payoffs to the seller of the Google call option vary with the stock price. Notice that for every dollar the buyer makes, the seller loses a dollar. Figure 20.2(*a*) is just Figure 20.1(*a*) drawn upside down.

In just the same way we can depict the position of an investor who sells, or writes, a put by standing Figure 20.1(*b*) on its head. The seller of the put has agreed to pay $430 for the share if the buyer of the put should request it. Clearly the seller will be safe as long as the share price remains above $430 but will lose money if the share price falls below this figure. The worst thing that can happen is that the stock becomes worthless. The seller would then be obliged to pay $430 for a stock worth $0. The payoff to the option position would be −$430.

Position Diagrams Are Not Profit Diagrams

Position diagrams show *only* the payoffs at option exercise; they do not account for the initial cost of buying the option or the initial proceeds from selling it.

This is a common point of confusion. For example, the position diagram in Figure 20.1(*a*) makes purchase of a call *look* like a sure thing—the payoff is at worst zero, with plenty of upside if Google's stock price goes above $430 by March 2009. But compare the *profit diagram* in Figure 20.3(*a*), which subtracts the $54.35 *cost* of the call in September 2008 from the payoff at maturity. The call buyer loses money at all share prices less than $430 + 54.35 = $484.35. Take another example: The position diagram in Figure 20.2(*b*) makes selling a put *look* like a sure loss—the *best* payoff is zero. But the profit diagram in Figure 20.3(*b*), which recognizes the $48.55 received by the seller, shows that the seller gains at all prices above $430 − 48.55 = $381.45.[5]

[4] The seller has some consolation, for he or she was paid $54.35 in September for selling the call.

[5] The fact that you have made a profit on your position is not necessarily a cause for rejoicing. The profit needs to compensate you for the time value of money and the risk that you took.

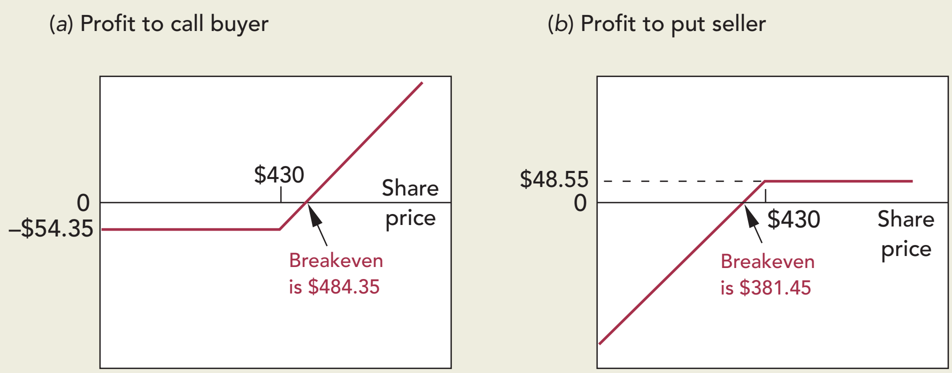


FIGURE 20.3

Profit diagrams incorporate the costs of buying an option or the proceeds from selling one. In panel (*a*), we subtract the $54.35 cost of the Google call from the payoffs plotted in Figure 20.1(*a*). In panel (*b*), we add the $48.55 proceeds from selling the Google put to the payoffs in Figure 20.2(*b*).

Profit diagrams like those in Figure 20.3 may be helpful to the options beginner, but options experts rarely draw them.[6] Now that you've graduated from the first options class we won't draw them either. We stick to position diagrams, because you have to focus on payoffs at exercise to understand options and to value them properly.

20-2 Financial Alchemy with Options

Look now at Figure 20.4(*a*), which shows the payoff if you buy Google stock at $430. You gain dollar-for-dollar if the stock price goes up and you lose dollar-for-dollar if it falls. That's trite; it doesn't take a genius to draw a 45-degree line.

Look now at panel (*b*), which shows the payoffs from an investment strategy that retains the upside potential of Google stock but gives complete downside protection. In this case your payoff stays at $430 even if the Google stock price falls to $400, $100, or zero. Panel (*b*)'s payoffs are clearly better than panel (*a*)'s. If a financial alchemist could turn panel (*a*) into panel (*b*), you'd be willing to pay for the service.

Of course alchemy has its dark side. Panel (*c*) shows an investment strategy for masochists. You lose if the stock price falls, but you give up any chance of profiting from a rise in the stock price. If you *like* to lose, or if someone pays you enough to take the strategy on, this is the investment for you.

Now, as you have probably suspected, all this financial alchemy is for real. You can do both the transmutations shown in Figure 20.4. You do them with options, and we will show you how.

Consider first the strategy for masochists. The first diagram in Figure 20.5 shows the payoffs from buying a share of Google stock, while the second shows the payoffs from *selling* a call option with a $430 exercise price. The third diagram shows what happens if you combine these two positions. The result is the no-win strategy that we depicted in panel

[6] Profit diagrams such as Figure 20.3 deduct the initial cost of the option from the final payoff. They therefore ignore the first lesson of finance—"A dollar today is worth more than a dollar in the future."

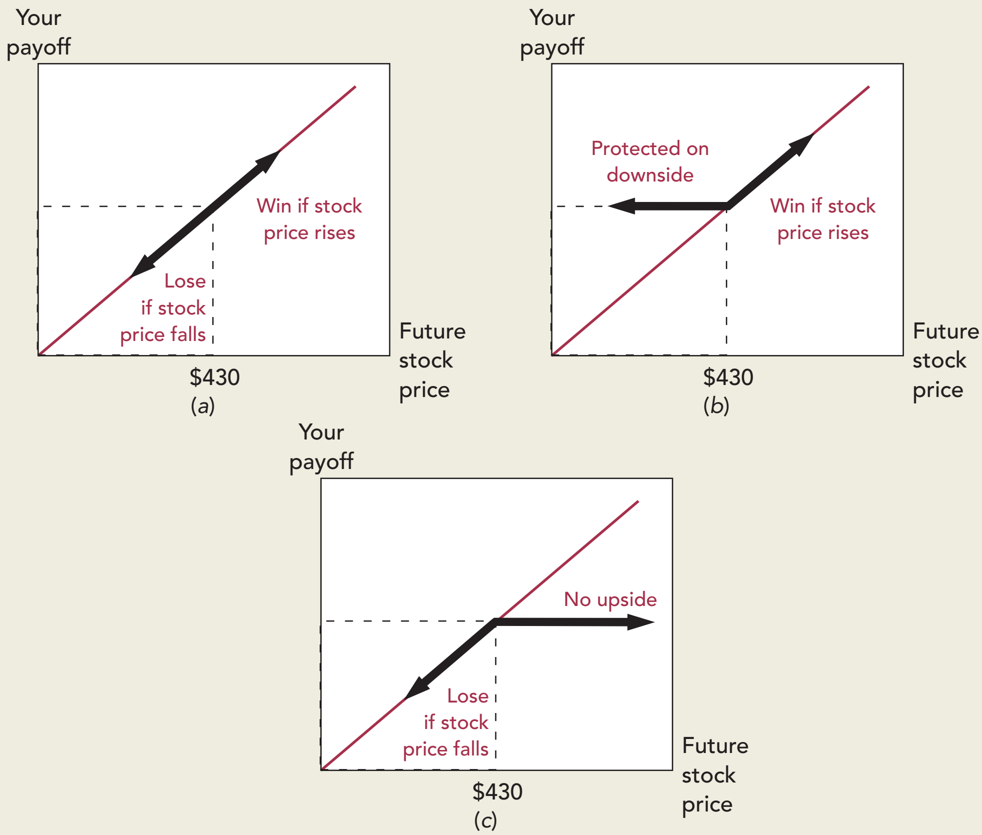


FIGURE 20.4

Payoffs at the end of six months to three investment strategies for Google stock. (*a*) You buy one share for $430. (*b*) No downside. If stock price falls, your payoff stays at $430. (*c*) A strategy for masochists? You lose if stock price falls, but you don't gain if it rises.

(*c*) of Figure 20.4. You lose if the stock price declines below $430, but, if the stock price rises above $430, the owner of the call will demand that you hand over your stock for the $430 exercise price. So you lose on the downside and give up any chance of a profit. That's the bad news. The good news is that you get paid for taking on this liability. In September 2009 you would have been paid $54.35, the price of a six-month call option.

Now, we'll create the downside protection shown in Figure 20.4(*b*). Look at row 1 of Figure 20.6. The first diagram again shows the payoff from buying a share of Google stock, while the next diagram in row 1 shows the payoffs from buying a Google put option with an exercise price of $430. The third diagram shows the effect of combining these two positions. You can see that, if Google's stock price rises above $430, your put option is valueless, so you simply receive the gains from your investment in the share. However, if the stock price falls below $430, you can exercise your put option and sell your stock for $430. Thus, by adding a put option to your investment in the stock, you have protected yourself against loss.[7] This is the strategy that we depicted in panel (*b*) of Figure 20.4. Of course,

[7] This combination of a stock and a put option is known as a *protective put*.

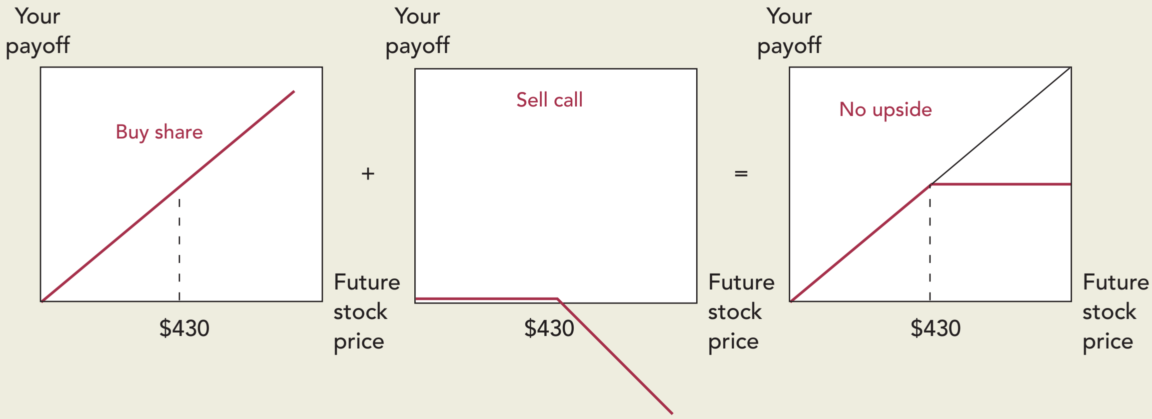


FIGURE 20.5

You can use options to create a strategy where you lose if the stock price falls but do not gain if it rises (strategy [*c*] in Figure 20.4).

there is no gain without pain. The *cost* of insuring yourself against loss is the amount that you pay for a put option on Google stock with an exercise price of $430. In September 2008 the price of this put was $48.55. This was the going rate for financial alchemists.

We have just seen how put options can be used to provide downside protection. We now show you how call options can be used to get the same result. This is illustrated in row 2 of Figure 20.6. The first diagram shows the payoff from placing the present value of $430 in a bank deposit. Regardless of what happens to the price of Google stock, your bank deposit will pay off $430. The second diagram in row 2 shows the payoff from a call option on Google stock with an exercise price of $430, and the third diagram shows the effect of combining these two positions. Notice that, if the price of Google stock falls, your call is worthless, but you still have your $430 in the bank. For every dollar that Google stock price rises above $430, your investment in the call option pays off an extra dollar. For example, if the stock price rises to $500, you will have $430 in the bank and a call worth $70. Thus you participate fully in any rise in the price of the stock, while being fully protected against any fall. So we have just found another way to provide the downside protection depicted in panel (*b*) of Figure 20.4.

These two rows of Figure 20.6 tell us something about the relationship between a call option and a put option. Regardless of the future stock price, both investment strategies provide identical payoffs. In other words, if you buy the share and a put option to sell it for $430, you receive the same payoff as from buying a call option and setting enough money aside to pay the $430 exercise price. Therefore, if you are committed to holding the two packages until the options expire, the two packages should sell for the same price today. This gives us a fundamental relationship for European options:

$$\text{Value of call} + \text{present value of exercise price} = \text{value of put} + \text{share price}$$

To repeat, this relationship holds because the payoff of

Buy call, invest present value of exercise price in safe asset[8]

is identical to the payoff from

Buy put, buy share

[8] The present value is calculated at the *risk-free* rate of interest. It is the amount that you would have to invest today in a bank deposit or Treasury bills to realize the exercise price on the option's expiration date.

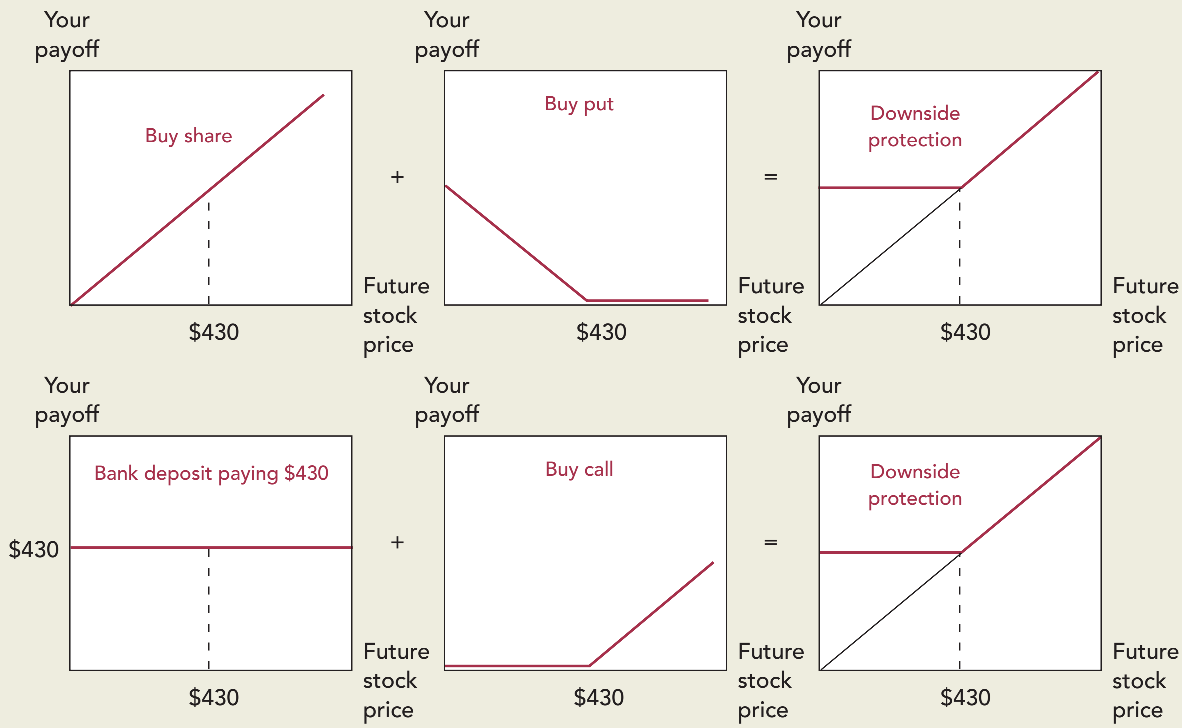


FIGURE 20.6

Each row in the figure shows a different way to create a strategy where you gain if the stock price rises but are protected on the downside (strategy [*b*] in Figure 20.4).

This basic relationship among share price, call and put values, and the present value of the exercise price is called **put–call parity.**[9]

Put–call parity can be expressed in several ways. Each expression implies two investment strategies that give identical results. For example, suppose that you want to solve for the value of a put. You simply need to twist the put–call parity formula around to give

$$\text{Value of put} = \text{value of call} + \text{present value of exercise price} - \text{share price}$$

From this expression you can deduce that

Buy put

is identical to

Buy call, invest present value of exercise price in safe asset, sell share

In other words, if puts are not available, you can get exactly the same payoff by buying calls, putting cash in the bank, and selling shares.

[9] Put–call parity holds only if you are committed to holding the options until the final exercise date. It therefore does not hold for American options, which you can exercise *before* the final date. We discuss possible reasons for early exercise in Chapter 21. Also if the stock makes a dividend payment before the final exercise date, you need to recognize that the investor who buys the call misses out on this dividend. In this case the relationship is

$$\text{Value of call} + \text{present value of exercise price} = \text{value of put} + \text{share price} - \text{present value of dividend}$$

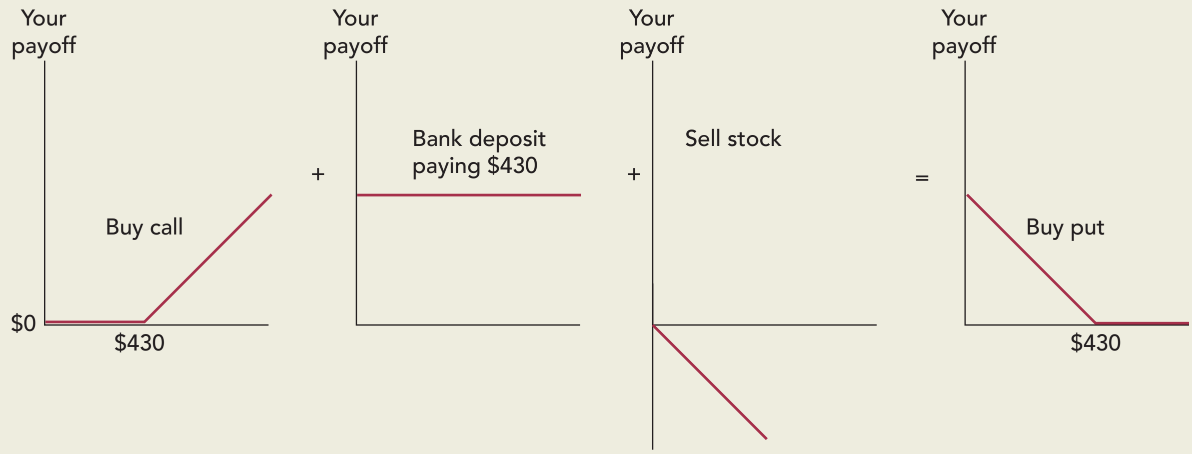


FIGURE 20.7

A strategy of buying a call, depositing the present value of the exercise price in the bank, and selling the stock is equivalent to buying a put.

If you find this difficult to believe, look at Figure 20.7, which shows the possible payoffs from each position. The diagram on the left shows the payoffs from a call option on Google stock with an exercise price of $430. The second diagram shows the payoffs from placing the present value of $430 in the bank. Regardless of what happens to the share price, this investment will pay off $430. The third diagram shows the payoffs from selling Google stock. When you sell a share that you don't own, you have a liability—you must sometime buy it back. As they say on Wall Street:

He who sells what isn't his'n
Buys it back or goes to pris'n

Therefore the best that can happen to you is that the share price falls to zero. In that case it costs you nothing to buy the share back. But for every extra dollar on the future share price, you will need to spend an extra dollar to buy the share. The final diagram in Figure 20.7 shows that the *total* payoff from these three positions is the same as if you had bought a put option. For example, suppose that when the option matures the stock price is $400. Your call will be worthless, your bank deposit will be worth $430, and it will cost you $400 to repurchase the share. Your total payoff is 0 + 430 − 400 = $30, exactly the same as the payoff from the put.

If two investments offer identical payoffs, then they should sell for the same price today. If the law of one price is violated, you have a potential arbitrage opportunity. So let's check whether there are any arbitrage profits to be made from our Google calls and puts. In September 2008 the price of a six-month call with a $430 exercise price was $54.35, the interest rate was about 3%, and the price of Google stock was $430. Therefore the cost of a homemade put was:

Buy call	+	present value of exercise price	−	share price	=	cost of homemade put
54.35	+	$430/1.03^{.5}$	−	430	=	48.04

This is almost exactly the same as it would have cost you to buy a put directly.

FIGURE 20.8

The payoff from one of Ms. Higden's "tickets" depends on Flatiron's stock price.

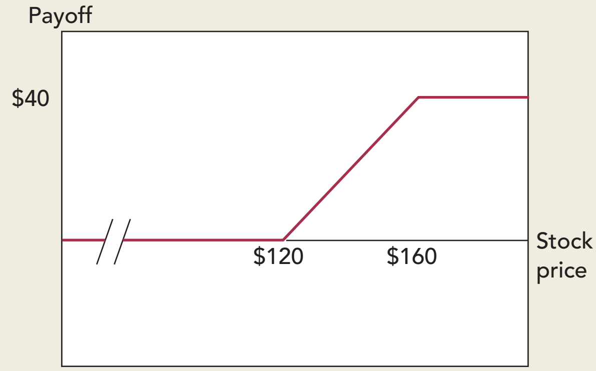
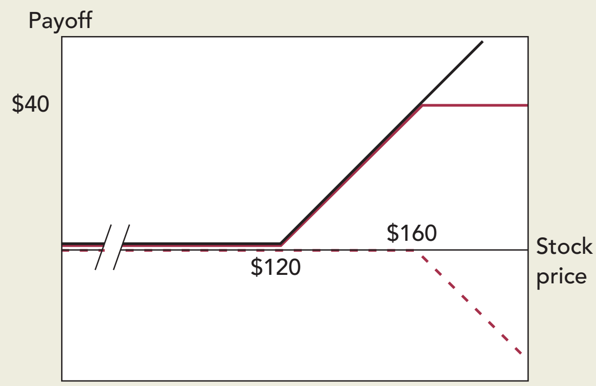


FIGURE 20.9

The solid black line shows the payoff from buying a call with an exercise price of $120. The dotted line shows the sale of a call with an exercise price of $160. The combined purchase and sale (shown by the colored line) is identical to one of Ms. Higden's "tickets."



Spotting the Option

Options rarely come with a large label attached. Often the trickiest part of the problem is to identify the option. When you are not sure whether you are dealing with a put or a call or a complicated blend of the two, it is a good precaution to draw a position diagram. Here is an example.

The Flatiron and Mangle Corporation has offered its president, Ms. Higden, the following incentive scheme: At the end of the year Ms. Higden will be paid a bonus of $50,000 for every dollar that the price of Flatiron stock exceeds its current figure of $120. However, the maximum bonus that she can receive is set at $2 million.

You can think of Ms. Higden as owning 50,000 tickets, each of which pays nothing if the stock price fails to beat $120. The value of each ticket then rises by $1 for each dollar rise in the stock price up to the maximum of $2,000,000/50,000 = $40. Figure 20.8 shows the payoffs from just one of these tickets. The payoffs are not the same as those of the simple put and call options that we drew in Figure 20.1, but it is possible to find a combination of options that exactly replicates Figure 20.8. Before going on to read the answer, see if you can spot it yourself. (If you are someone who enjoys puzzles of the make-a-triangle-from-just-two-matchsticks type, this one should be a walkover.)

The answer is in Figure 20.9. The solid black line represents the purchase of a call option with an exercise price of $120, and the dotted line shows the sale of another call option with an exercise price of $160. The colored line shows the payoffs from a combination of the purchase and the sale—exactly the same as the payoffs from one of Ms. Higden's tickets.

Thus, if we wish to know how much the incentive scheme is costing the company, we need to calculate the difference between the value of 50,000 call options with an exercise price of $120 and the value of 50,000 calls with an exercise price of $160.

We could have made the incentive scheme depend in a much more complicated way on the stock price. For example, the bonus could peak at $2 million and then fall steadily back to zero as the stock price climbs above $160.[10] You could still have represented this scheme as a combination of options. In fact, we can state a general theorem:

> Any set of contingent payoffs—that is, payoffs that depend on the value of some other asset—can be constructed with a mixture of simple options on that asset.

In other words, you can create any position diagram—with as many ups and downs or peaks and valleys as your imagination allows—by buying or selling the right combinations of puts and calls with different exercise prices.[11]

Finance pros often talk about **financial engineering,** which is the practice of packaging different investments to create new tailor-made instruments. Perhaps a German company would like to set a minimum and maximum cost at which it can buy dollars in six-months' time. Or perhaps an oil company would like to pay a lower rate of interest on its debt if the price of oil falls. Options provide the building blocks that financial engineers use to create these interesting payoff structures.

20-3 What Determines Option Values?

So far we have said nothing about how the market value of an option is determined. We do know what an option is worth when it matures, however. Consider, for instance, our earlier example of an option to buy Google stock at $430. If Google's stock price is below $430 on the exercise date, the call will be worthless; if the stock price is above $430, the call will be worth $430 less than the value of the stock. This relationship is depicted by the heavy, lower line in Figure 20.10.

Even before maturity the price of the option can never remain *below* the heavy, lower-bound line in Figure 20.10. For example, if our option were priced at $10 and the stock were priced at $460, it would pay any investor to sell the stock and then buy it back by purchasing the option and exercising it for an additional $430. That would give an arbitrage opportunity with a profit of $20. The demand for options from investors seeking to exploit this opportunity would quickly force the option price up, at least to the heavy line in the figure. For options that still have some time to run, the heavy line is therefore a *lower bound* on the market price of the option. Option geeks express the same idea more concisely when they write Lower Bound = Max(stock price − exercise price, 0).

The diagonal line in Figure 20.10 is the *upper bound* to the option price. Why? Because the option cannot give a higher ultimate payoff than the stock. If at the option's expiration the stock price ends up *above* the exercise price, the option is worth the stock price *less* the exercise price.

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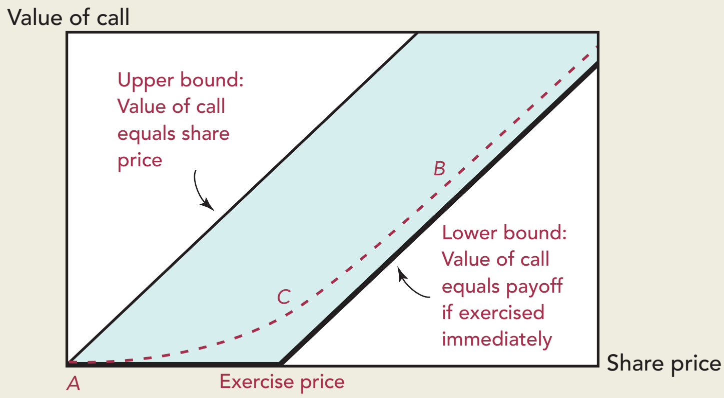
[10] This is not as nutty a bonus scheme as it may sound. Maybe Ms. Higden's hard work can lift the value of the stock by so much and the only way she can hope to increase it further is by taking on extra risk. You can deter her from doing this by making her bonus start to decline beyond some point. Too bad that the bonus schemes for some bank CEOs did not contain this feature.

[11] In some cases you may also have to borrow or lend money to generate a position diagram with your desired pattern. Lending raises the payoff line in position diagrams, as in the bottom row of Figure 20.6. Borrowing lowers the payoff line.

FIGURE 20.10

Value of a call before its expiration date (dashed line). The value depends on the stock price. It is always worth more than its value if exercised now (heavy line). It is never worth more than the stock price itself.



If the stock price ends up *below* the exercise price, the option is worthless, but the stock's owner still has a valuable security. For example, if the option's exercise price is $430, then the extra dollar returns realized by stockholders are shown in the following table:

	Stock Payoff	Option Payoff	Extra Payoff from Holding Stock Instead of Option
Option exercised (stock price greater than $430)	Stock price	Stock price − 430	$430
Option expires unexercised (stock price less than or equal to $430)	Stock price	0	Stock price

If the stock and the option have the same price, everyone will rush to sell the option and buy the stock. Therefore, the option price must be somewhere in the shaded region of Figure 20.10. In fact, it will lie on a curved, upward-sloping line like the dashed curve shown in the figure. This line begins its travels where the upper and lower bounds meet (at zero). Then it rises, gradually becoming parallel to the upward-sloping part of the lower bound.

But let us look more carefully at the shape and location of the dashed line. Three points, *A*, *B*, and *C*, are marked on the dashed line. As we explain each point you will see why the option price has to behave as the dashed line predicts.

Point *A* *When the stock is worthless, the option is worthless.* A stock price of zero means that there is no possibility the stock will ever have any future value.[12] If so, the option is sure to expire unexercised and worthless, and it is worthless today.

That brings us to our first important point about option value:

The value of an option increases as stock price increases, if the exercise price is held constant.

That should be no surprise. Owners of call options clearly hope for the stock price to rise and are happy when it does.

Point *B* *When the stock price becomes large, the option price approaches the stock price less the present value of the exercise price.* Notice that the dashed line representing the option price

[12] If a stock *can* be worth something in the future, then investors will pay *something* for it today, although possibly a very small amount.

in Figure 20.10 eventually becomes parallel to the ascending heavy line representing the lower bound on the option price. The reason is as follows: The higher the stock price, the higher is the probability that the option will eventually be exercised. If the stock price is high enough, exercise becomes a virtual certainty; the probability that the stock price will fall below the exercise price before the option expires becomes trivially small.

If you own an option that you *know* will be exchanged for a share of stock, you effectively own the stock now. The only difference is that you don't have to pay for the stock (by handing over the exercise price) until later, when formal exercise occurs. In these circumstances, buying the call is equivalent to buying the stock but financing part of the purchase by borrowing. The amount implicitly borrowed is the present value of the exercise price. The value of the call is therefore equal to the stock price less the present value of the exercise price.

This brings us to another important point about options. Investors who acquire stock by way of a call option are buying on credit. They pay the purchase price of the option today, but they do not pay the exercise price until they actually take up the option. The delay in payment is particularly valuable if interest rates are high and the option has a long maturity.

Thus, the value of an option increases with both the rate of interest and the time to maturity.

Point *C* *The option price always exceeds its minimum value* (except when stock price is zero). We have seen that the dashed and heavy lines in Figure 20.10 coincide when stock price is zero (point *A*), but elsewhere the lines diverge; that is, the option price must exceed the minimum value given by the heavy line. The reason for this can be understood by examining point *C*.

At point *C*, the stock price exactly equals the exercise price. The option is therefore worthless if exercised today. However, suppose that the option will not expire until three months hence. Of course we do not know what the stock price will be at the expiration date. There is roughly a 50% chance that it will be higher than the exercise price and a 50% chance that it will be lower. The possible payoffs to the option are therefore:

Outcome	Payoff
Stock price rises (50% probability)	Stock price less exercise price (option is exercised)
Stock price falls (50% probability)	Zero (option expires worthless)

If there is a positive probability of a positive payoff, and if the worst payoff is zero, then the option must be valuable. That means the option price at point *C* exceeds its lower bound, which at point *C* is zero. In general, the option prices will exceed their lower-bound values as long as there is time left before expiration.

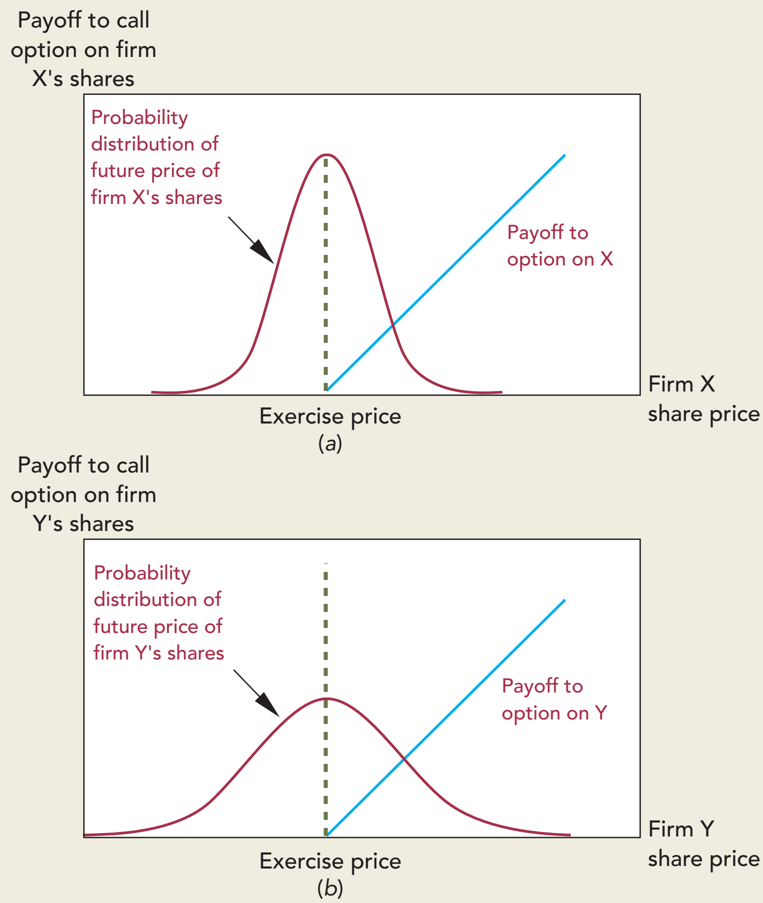
One of the most important determinants of the *height* of the dashed curve (i.e., of the difference between actual and lower-bound value) is the likelihood of substantial movements in the stock price. An option on a stock whose price is unlikely to change by more than 1% or 2% is not worth much; an option on a stock whose price may halve or double is very valuable.

As an option holder, you gain from volatility because the payoffs are not symmetric. If the stock price falls *below* the exercise price, your call option will be worthless, regardless of whether the shortfall is a few cents or many dollars. On the other hand, for every dollar that the stock price rises *above* the exercise price, your call will be worth an extra dollar. Therefore, the option holder gains from the increased volatility on the upside, but does not lose on the downside.

A simple example may help to illustrate the point. Consider two stocks, X and Y, each of which is priced at $100. The only difference is that the outlook for Y is much less easy

FIGURE 20.11

Call options on the shares of (*a*) firm X and (*b*) firm Y. In each case, the current share price equals the exercise price, so each option has a 50% chance of ending up worthless (if the share price falls) and a 50% chance of ending up "in the money" (if the share price rises). However, the chance of a large payoff is greater for the option on firm Y's shares because Y's stock price is more volatile and therefore has more upside potential.



to predict. There is a 50% chance that the price of Y will rise to $150 and a similar chance that it will fall to $70. By contrast, there is a 50-50 chance that the price of X will either rise to $130 or fall to $90.

Suppose that you are offered a call option on each of these stocks with an exercise price of $100. The following table compares the possible payoffs from these options:

	Stock Price Falls	Stock Price Rises
Payoff from option on X	$0	$130 − $100 = $30
Payoff from option on Y	$0	$150 − $100 = $50

In both cases there is a 50% chance that the stock price will decline and make the option worthless but, if the stock price rises, the option on Y will give the larger payoff. Since the chance of a zero payoff is the same, the option on Y is worth more than the option on X.

Of course, in practice future stock prices may take on a range of different values. We have recognized this in Figure 20.11, where the uncertain outlook for Y's stock price shows up in the wider probability distribution of future prices.[13] The greater spread of outcomes

[13] Figure 20.11 continues to assume that the exercise price on both options is equal to the current stock price. This is not a necessary assumption. Also in drawing Figure 20.11 we have assumed that the distribution of stock prices is symmetric. This also is not a necessary assumption, and we will look more carefully at the distribution of stock prices in the next chapter.

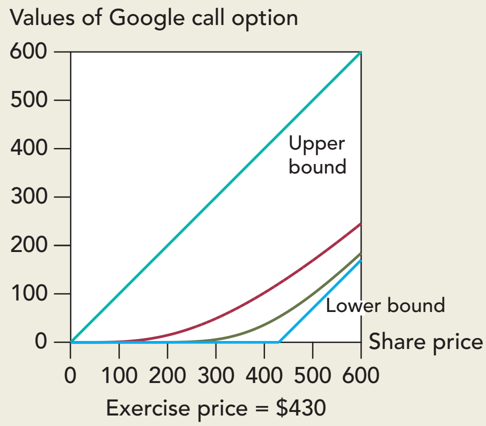


FIGURE 20.12

How the value of the Google call option increases with the volatility of the stock price. Each of the curved lines shows the value of the option for different initial stock prices. The only difference is that the upper line assumes a much higher level of uncertainty about Google's future stock price.

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for stock Y again provides more upside potential and therefore increases the chance of a large payoff on the option.

Figure 20.12 shows how volatility affects the value of an option. The upper curved line depicts the value of the Google call option assuming that Google's stock price, like that of stock Y, is highly variable. The lower curved line assumes a lower (and more realistic) degree of volatility.[14]

The probability of large stock price changes during the remaining life of an option depends on two things: (1) the variance (i.e., volatility) of the stock price *per period* and (2) the number of periods until the option expires. If there are t remaining periods, and the variance per period is σ^2, the value of the option should depend on cumulative variability $\sigma^2 t$.[15] Other things equal, you would like to hold an option on a volatile stock (high σ^2). Given volatility, you would like to hold an option with a long life ahead of it (large t).

Thus the value of an option increases with both the volatility of the share price and the time to maturity.

It's a rare person who can keep all these properties straight at first reading. Therefore, we have summed them up in Table 20.2.

Risk and Option Values

In most financial settings, risk is a bad thing; you have to be paid to bear it. Investors in risky (high-beta) stocks demand higher expected rates of return. High-risk capital investment projects have correspondingly high costs of capital and have to beat higher hurdle rates to achieve positive NPV.

[14] The option values shown in Figure 20.12 were calculated by using the Black-Scholes option-valuation model. We explain this model in Chapter 21 and use it to value the Google option.

[15] Here is an intuitive explanation: If the stock price follows a random walk (see Section 13-2), successive price changes are statistically independent. The cumulative price change before expiration is the sum of t random variables. The variance of a sum of independent random variables is the sum of the variances of those variables. Thus, if σ^2 is the variance of the daily price change, and there are t days until expiration, the variance of the cumulative price change is $\sigma^2 t$.

TABLE 20.2

What the price of a call option depends on.

* The direct effect of increases in r_f or σ on option price, *given* the stock price. There may also be *indirect* effects. For example, an increase in r_f could reduce stock price P. This in turn could affect option price.

1. If there is an *increase* in:	The change in the call option price is:
Stock price (P)	Positive
Exercise price (EX)	Negative
Interest rate (r_f)	Positive*
Time to expiration (t)	Positive
Volatility of stock price (σ)	Positive*

2. Other properties of call options:
   a. *Upper bound.* The option price is always less than the stock price.
   b. *Lower bound.* The call price never falls below the payoff to immediate exercise ($P - EX$ or zero, whichever is larger).
   c. If the stock is worthless, the call is worthless.
   d. As the stock price becomes very large, the call price approaches the stock price less the present value of the exercise price.

TABLE 20.3

Which package of executive stock options would you choose? The package offered by Digital Organics is more valuable, because the volatility of that company's stock is higher.

	Establishment Industries	Digital Organics
Number of options	100,000	100,000
Exercise price	$25	$25
Maturity	5 years	5 years
Current stock price	$22	$22
Stock price volatility (standard deviation of return)	24%	36%

For options it's the other way around. As we have just seen, options written on volatile assets are worth *more* than options written on safe assets. If you can understand and remember that one fact about options, you've come a long way.

EXAMPLE 20.1 ● Volatility and Executive Stock Options

Suppose you have to choose between two job offers, as CFO of either Establishment Industries or Digital Organics. Establishment Industries' compensation package includes a grant of the stock options described on the left side of Table 20.3. You demand a similar package from Digital Organics, and they comply. In fact they match the Establishment Industries options in every respect, as you can see on the right side of Table 20.3. (The two companies' current stock prices just happen to be the same.) The only difference is that Digital Organics' stock is 50% more volatile than Establishment Industries' stock (36% annual standard deviation vs. 24% for Establishment Industries).

If your job choice hinges on the value of the executive stock options, you should take the Digital Organics offer. The Digital Organics options are written on the more volatile asset and therefore are worth more.

We value the two stock-option packages in the next chapter.

SUMMARY

If you have managed to reach this point, you are probably in need of a rest and a stiff gin and tonic. So we will summarize what we have learned so far and take up the subject of options again in the next chapter when you are rested (or drunk).

There are two types of option. An American call is an option to buy an asset at a specified exercise price on or before a specified maturity date. Similarly, an American put is an option to sell the asset at a specified price on or before a specified date. European calls and puts are exactly the same except that they cannot be exercised before the specified maturity date. Calls and puts are the basic building blocks that can be combined to give any pattern of payoffs.

What determines the value of a call option? Common sense tells us that it ought to depend on three things:

1. To exercise an option you have to pay the exercise price. Other things being equal, the less you are obliged to pay, the better. Therefore, the value of a call option increases with the ratio of the asset price to the exercise price.
2. You do not have to pay the exercise price until you decide to exercise the option. Therefore, a call option gives you a free loan. The higher the rate of interest and the longer the time to maturity, the more this free loan is worth. So the value of a call option increases with the interest rate and time to maturity.
3. If the price of the asset falls short of the exercise price, you won't exercise the call option. You will, therefore, lose 100% of your investment in the option no matter how far the asset depreciates below the exercise price. On the other hand, the more the price rises *above* the exercise price, the more profit you will make. Therefore the option holder does not lose from increased volatility if things go wrong, but gains if they go right. The value of an option increases with the variance per period of the stock return multiplied by the number of periods to maturity.

Always remember that an option written on a risky (high-variance) asset is worth more than an option on a safe asset. It's easy to forget, because in most other financial contexts increases in risk reduce present value.

FURTHER READING

See Further Readings for Chapter 21.

PROBLEM SETS

Mc Graw Hill connect™

Select problems are available in McGraw-Hill Connect. Please see the preface for more information.

BASIC

1. Complete the following passage:

   A _______ option gives its owner the opportunity to buy a stock at a specified price that is generally called the _______ price. A _______ option gives its owner the opportunity to sell stock at a specified price. Options that can be exercised only at maturity are called _______ options.

2. Note Figure 20.13 on the next page. Match each diagram, (*a*) and (*b*), with one of the following positions:

   - Call buyer
   - Call seller
   - Put buyer
   - Put seller

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3. Suppose that you hold a share of stock and a put option on that share. What is the payoff when the option expires if (a) the stock price is below the exercise price? (b) the stock price is above the exercise price?

4. What is put–call parity and why does it hold? Could you apply the parity formula to a call and put with different exercise prices?

5. There is another strategy involving calls and borrowing or lending that gives the same payoffs as the strategy described in Problem 3. What is the alternative strategy?

6. Dr. Livingstone I. Presume holds £600,000 in East African gold stocks. Bullish as he is on gold mining, he requires absolute assurance that at least £500,000 will be available in six months to fund an expedition. Describe two ways for Dr. Presume to achieve this goal. There is an active market for puts and calls on East African gold stocks, and the rate of interest is 6% per year.

7. Suppose you buy a one-year European call option on Wombat stock with an exercise price of $100 and sell a one-year European put option with the same exercise price. The current stock price is $100, and the interest rate is 10%.
   a. Draw a position diagram showing the payoffs from your investments.
   b. How much will the combined position cost you? Explain.

8. Look again at Figure 20.13. It appears that the investor in panel (*b*) can't lose and the investor in panel (*a*) can't win. Is that correct? Explain. (*Hint:* Draw a profit diagram for each panel.)

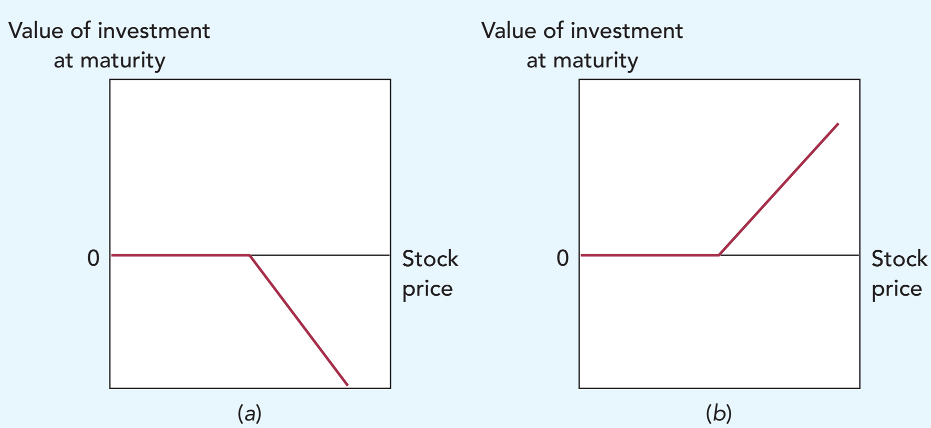
9. What is a call option worth if (a) the stock price is zero? (b) the stock price is extremely high relative to the exercise price?

10. How does the price of a call option respond to the following changes, other things equal? Does the call price go up or down?
    a. Stock price increases.
    b. Exercise price is increased.
    c. Risk-free rate increases.
    d. Expiration date of the option is extended.
    e. Volatility of the stock price falls.
    f. Time passes, so the option's expiration date comes closer.

11. Respond to the following statements.
    a. "I'm a conservative investor. I'd much rather hold a call option on a safe stock like Exxon Mobil than a volatile stock like Google."

FIGURE 20.13

See Problem 2.



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b. "I bought an American call option on Fava Farms stock, with an exercise price of $45 per share and three more months to maturity. Fava Farms' stock has skyrocketed from $35 to $55 per share, but I'm afraid it will fall back below $45. I'm going to lock in my gain and exercise my call right now."

INTERMEDIATE

12. Discuss briefly the risks and payoffs of the following positions:

a. Buy stock and a put option on the stock.

b. Buy stock.

c. Buy call.

d. Buy stock and sell call option on the stock.

e. Buy bond.

f. Buy stock, buy put, and sell call.

g. Sell put.

13. "The buyer of the call and the seller of the put both hope that the stock price will rise. Therefore the two positions are identical." Is the speaker correct? Illustrate with a position diagram.

14. Pintail's stock price is currently $200. A one-year *American* call option has an exercise price of $50 and is priced at $75. How would you take advantage of this great opportunity? Now suppose the option is a *European* call. What would you do?

15. It is possible to buy three-month call options and three-month puts on stock Q. Both options have an exercise price of $60 and both are worth $10. If the interest rate is 5% a year, what is the stock price? (*Hint:* Use put–call parity.)

16. In January 2009, a one-year call on the stock of Amazon.com, with an exercise price of $45.00, sold for $19.55. The stock price was $55. The risk-free interest rate was 2.5%. How much would you be willing to pay for a put on Amazon stock with the same maturity and exercise price? Assume that the Amazon options are European options. (*Note:* Amazon does not pay a dividend.)

17. FX Bank has succeeded in hiring ace foreign exchange trader Lucinda Cable. Her remuneration package reportedly includes an annual bonus of 20% of the profits that she generates in excess of $100 million. Does Ms. Cable have an option? Does it provide her with the appropriate incentives?

18. Suppose that Mr. Colleoni borrows the present value of $100, buys a six-month put option on stock Y with an exercise price of $150, and sells a six-month put option on Y with an exercise price of $50.

a. Draw a position diagram showing the payoffs when the options expire.

b. Suggest two other combinations of loans, options, and the underlying stock that would give Mr. Colleoni the same payoffs.

19. Which *one* of the following statements is correct?

a. Value of put + present value of exercise price = value of call + share price.

b. Value of put + share price = value of call + present value of exercise price.

c. Value of put − share price = present value of exercise price − value of call.

d. Value of put + value of call = share price − present value of exercise price.

The correct statement equates the value of two investment strategies. Plot the payoffs to each strategy as a function of the stock price. Show that the two strategies give identical payoffs.

20. Test the formula linking put and call prices by using it to explain the relative prices of actual traded puts and calls. (*Note:* The formula is exact only for European options. Most traded puts and calls are American.)

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21. a. If you can't sell a share short, you can achieve exactly the same final payoff by a combination of options and borrowing or lending. What is this combination?

b. Now work out the mixture of stock and options that gives the same final payoff as investment in a risk-free loan.

22. The common stock of Triangular File Company is selling at $90. A 26-week call option written on Triangular File's stock is selling for $8. The call's exercise price is $100. The risk-free interest rate is 10% per year.

a. Suppose that puts on Triangular stock are not traded, but you want to buy one. How would you do it?

b. Suppose that puts *are* traded. What should a 26-week put with an exercise price of $100 sell for?

23. Ms. Higden has been offered yet another incentive scheme (see Section 20-2). She will receive a bonus of $500,000 if the stock price at the end of the year is $120 or more; otherwise she will receive nothing. (Don't ask why anyone should want to offer such an arrangement. Maybe there's some tax angle.)

a. Draw a position diagram illustrating the payoffs from such a scheme.

b. What combination of options would provide these payoffs? (*Hint:* You need to buy a large number of options with one exercise price and sell a similar number with a different exercise price.)

24. Option traders often refer to "straddles" and "butterflies." Here is an example of each:

- *Straddle:* Buy call with exercise price of $100 and simultaneously buy put with exercise price of $100.
- *Butterfly:* Simultaneously buy one call with exercise price of $100, sell two calls with exercise price of $110, and buy one call with exercise price of $120.

Draw position diagrams for the straddle and butterfly, showing the payoffs from the investor's net position. Each strategy is a bet on variability. Explain briefly the nature of each bet.

25. Look at actual trading prices of call options on stocks to check whether they behave as the theory presented in this chapter predicts. For example,

a. Follow several options as they approach maturity. How would you expect their prices to behave? Do they actually behave that way?

b. Compare two call options written on the same stock with the same maturity but different exercise prices.

c. Compare two call options written on the same stock with the same exercise price but different maturities.

26. Is it more valuable to own an option to buy a portfolio of stocks or to own a portfolio of options to buy each of the individual stocks? Say briefly why.

27. Table 20.4 lists some prices of options on common stocks (prices are quoted to the nearest dollar). The interest rate is 10% a year. Can you spot any mispricing? What would you do to take advantage of it?

TABLE 20.4

Prices of options on common stocks (in dollars). See Problem 27.

Stock	Time to Exercise (months)	Exercise Price	Stock Price	Put Price	Call Price
Drongo Corp.	6	$ 50	$80	$20	$52
Ragwort, Inc.	6	100	80	10	15
Wombat Corp.	3	40	50	7	18
	6	40	50	5	17
	6	50	50	8	10

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28. You've just completed a month-long study of energy markets and conclude that energy prices will be *much* more volatile in the next year than historically. Assuming you're right, what types of option strategies should you undertake? (*Note:* You can buy or sell options on oil-company stocks or on the price of future deliveries of crude oil, natural gas, fuel oil, etc.)

CHALLENGE

29. Figure 20.14 below shows some complicated position diagrams. Work out the combination of stocks, bonds, and options that produces each of these positions.

30. Some years ago the Australian firm Bond Corporation sold a share in some land that it owned near Rome for $110 million and as a result boosted its annual earnings by $74 million. A television program subsequently revealed that the buyer was given a put option to sell its share in the land back to Bond for $110 million and that Bond had paid $20 million for a call option to repurchase the share in the land for the same price.

a. What happens if the land is worth more than $110 million when the options expire? What if it is worth less than $110 million?

b. Use position diagrams to show the net effect of the land sale and the option transactions.

c. Assume a one-year maturity on the options. Can you deduce the interest rate?

d. The television program argued that it was misleading to record a profit on the sale of land. What do you think?

31. Three six-month call options are traded on Hogswill stock:

Exercise Price	Call Option Price
$ 90	$ 5
100	11
110	15

How would you make money by trading in Hogswill options? (*Hint:* Draw a graph with the option price on the vertical axis and the ratio of stock price to exercise price on the horizontal axis. Plot the three Hogswill options on your graph. Does this fit with what you know about how option prices should vary with the ratio of stock price to exercise price?) Now look in the newspaper at options with the same maturity but different exercise prices. Can you find any money-making opportunities?

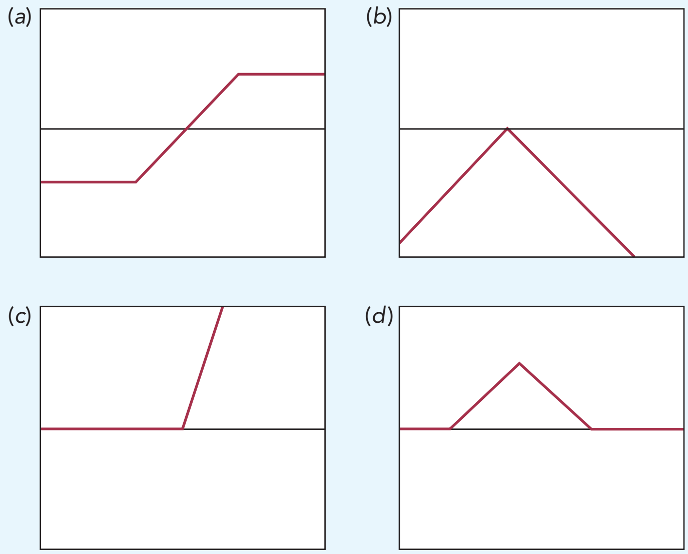

FIGURE 20.14

Some complicated position diagrams. See Problem 29.

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32. Digital Organics has 10 million outstanding shares trading at $25 per share. It also has a large amount of debt outstanding, all coming due in one year. The debt pays interest at 8%. It has a par (face) value of $350 million, but is trading at a market value of only $280 million. The one-year risk-free interest rate is 6%.

a. Write out the put–call parity formula for Digital Organics' stock, debt, and assets.

b. What is the value of the company's option to default on its debt?

REAL-TIME DATA ANALYSIS

Go to **finance.yahoo.com**. Check out the delayed quotes for Google for different exercise prices and maturities.

a. Confirm that higher exercise prices mean lower call prices and higher put prices.

b. Confirm that longer maturity means higher prices for both puts and calls.

c. Choose a Google put and call with the same exercise price and maturity. Confirm that put–call parity holds (approximately). (*Note:* You will have to use an up-to-date risk-free interest rate.)

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